

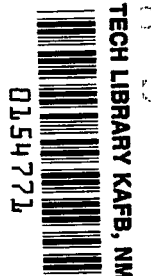
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WIND-TUNNEL PRESSURE MEASUREMENTS IN THE WAKE OF A CONE-CYLINDER MODEL AT MACH NUMBERS OF 2.30 AND 4.65

by John T. McShera, Jr.

Langley Research Center

Langley Station, Hampton, Va.

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SUMMARY

An investigation of the flow field behind a simple cone-cylinder body of revolution has been conducted at Mach numbers of 2.30 and 4.65. The results include local total- and static-pressure measurements in the wake.

The results of the pressure distributions indicated that the use of thin struts to mount the wind-tunnel model had little or no effect on the wake characteristics behind the model. The distribution of total pressure in the wake throat region behind the model was extremely nonuniform and such characteristics would exert an unstable influence on a decelerator in the flow field. The total pressure loss near the center line in the wake of the model significantly increased with an increase in Mach number.

INTRODUCTION

Numerous investigations, both in wind tunnels and under free-flight conditions at supersonic speeds, have shown that many parameters affect the drag and stability characteristics of towed decelerators. Results of a number of wind-tunnel tests of such configurations may be found in references 1 to 6. Among the factors affecting decelerator performance are forebody geometry, decelerator size, and location of the decelerator in the wake of the towing vehicle. The effects of these three factors on decelerator performance indicate that a knowledge of the wake characteristics behind a given model configuration is a fundamental prerequisite for the design of an efficient decelerator for use at supersonic speeds.

The flow field in the wake of a body or vehicle is not readily predictable and therefore experimental means are necessary to determine these wake characteristics. The wind tunnel has been used extensively as a means for conducting decelerator investigations; however, there has been a question of data validity because of model-support effects on the wake characteristics.

Accordingly, a preliminary investigation has been performed in the Langley Unitary Plan wind tunnel at Mach numbers of 2.30 and 4.65 to determine the wake characteristics (in terms of total- and static-pressure measurements) behind a simple cone-cylinder body. The body was mounted on a strut in the tunnel in such a manner that the magnitude of the effects of the support system on the wake characteristics could also be assessed. The investigation was performed at a Reynolds number per foot of 1.6×10^6 .

SYMBOLS

M_∞	free-stream Mach number
p	static pressure, lb/sq ft
p_t	total pressure behind a normal shock wave, lb/sq ft
x	longitudinal distance downstream from model base, in.
y	lateral distance from model center line, in.
z	vertical distance from model center line, in.

APPARATUS

Wind Tunnel

The tests were conducted in the high Mach number test section of the Langley Unitary Plan wind tunnel. The test section is of the variable-pressure return-flow type and is 4 feet square and approximately 7 feet in length. The nozzle leading to the test section is of the asymmetric sliding-block type, and the Mach number may be varied continuously through a range from about 2.30 to 4.65. Further details of the wind tunnel may be found in reference 7.

Models and Instrumentation

A sketch of the test section, model support system, and pressure-rake installation is shown in figure 1. The support system consisted of two thin struts which spanned the tunnel in the horizontal plane and held the model in the center of the tunnel. The model used is a cone-cylinder configuration 25.5 inches long. The base of the cylinder is 2.38 inches in diameter. Dimensional details of this model and the rake used for measuring pressures in the wake flow field are shown in figure 2. The pressure rake was 5 inches high and had 21 total-pressure probes $1/4$ inch apart and 5 evenly spaced static-pressure probes.

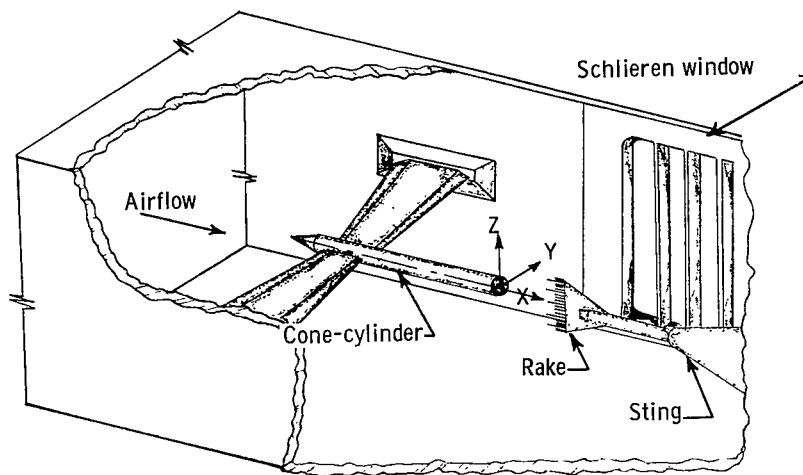
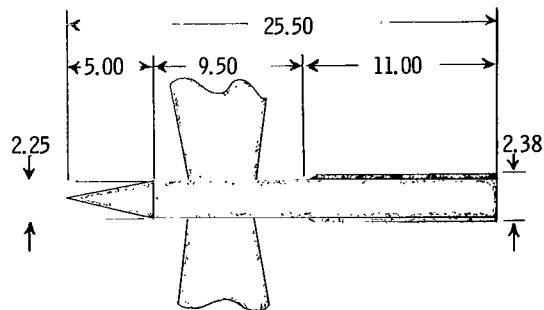
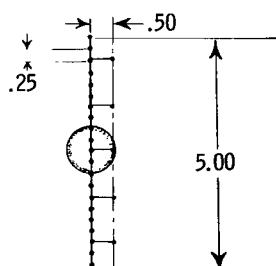


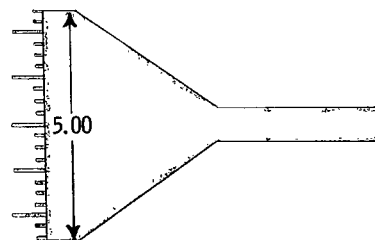
Figure 1.- Sketch of model installation.



Cone-cylinder



Rear view of rake



Side view of rake

Figure 2.- Dimensional details of pressure rake and cone-cylinder. (All dimensions in inches.)

TESTS AND ACCURACY

The tests were performed at Mach numbers of 2.30 and 4.65 at a dynamic pressure of 350 lb/sq ft. The dewpoint temperature was maintained below -30° F to prevent any significant condensation effect. The stagnation temperature was maintained at 150° F for $M_{\infty} = 2.30$ and at 175° F for $M_{\infty} = 4.65$. The pressure in the wake of the payload was measured by means of electrically actuated pressure scanning valves that recorded essentially instantaneous values. With the rake mounted vertically in the tunnel, the test procedure consisted of setting the rake pressure measuring plane at a given distance x behind the base of the cone-cylinder model and then traversing the rake in a lateral plane a distance y from the model center line to $y = 2.5$ inches; the pressure data were taken at discretely measured lateral distances. The procedure was performed at longitudinal locations from $x = 0.5$ to 18 inches.

The accuracy of the individual quantities is estimated to be within the following limits:

p_t , lb/sq ft	± 20
p , lb/sq ft	± 7
x , in.	0.01
y , in.	0.01
$M_{\infty} = 2.30$	± 0.015
$M_{\infty} = 4.65$	± 0.05

DISCUSSION

The results of the investigation are presented in the form of total and static pressures. Figure 3 shows the vertical distribution of total pressure at $y = 0$ and at longitudinal distances behind the model from $x = 0.5$ to 18 inches. These data are for free-stream Mach numbers of 2.30 and 4.65. At longitudinal locations of $x = 0.5$, 1.0, and 2.0 inches and vertical locations at or near $z = 0$, the total pressures for both Mach numbers are essentially equal to the model base static pressure. This condition would be expected since considerable information is available that shows a no-flow condition at the base of a model and a reverse flow at small distances rearward of the base of a model. This region behind a model base is sometimes referred to as the "dead-air region." At longitudinal locations of $x = 6.0$, 12.0, and 18.0 inches and near $z = 0$, there is an increase in total pressure with increasing distance downstream of the model. This pressure increase is, of course, due to a mixing action of the streamflow with the core of air behind the model. The increase in total pressure near the center line is not nearly as great at $M_{\infty} = 4.65$ as at $M_{\infty} = 2.30$. In addition, the central core of airflow which has an essentially level pressure at $M_{\infty} = 2.30$ appears to have a well-defined minimum point of pressure at $M_{\infty} = 4.65$. (The offset of this minimum point from the $z = 0$ location is due to tunnel airflow misalignment.) On either side of the minimum total-pressure regions, at both test Mach numbers, there is a rapid increase in p_t , with the values of total pressure approaching those for

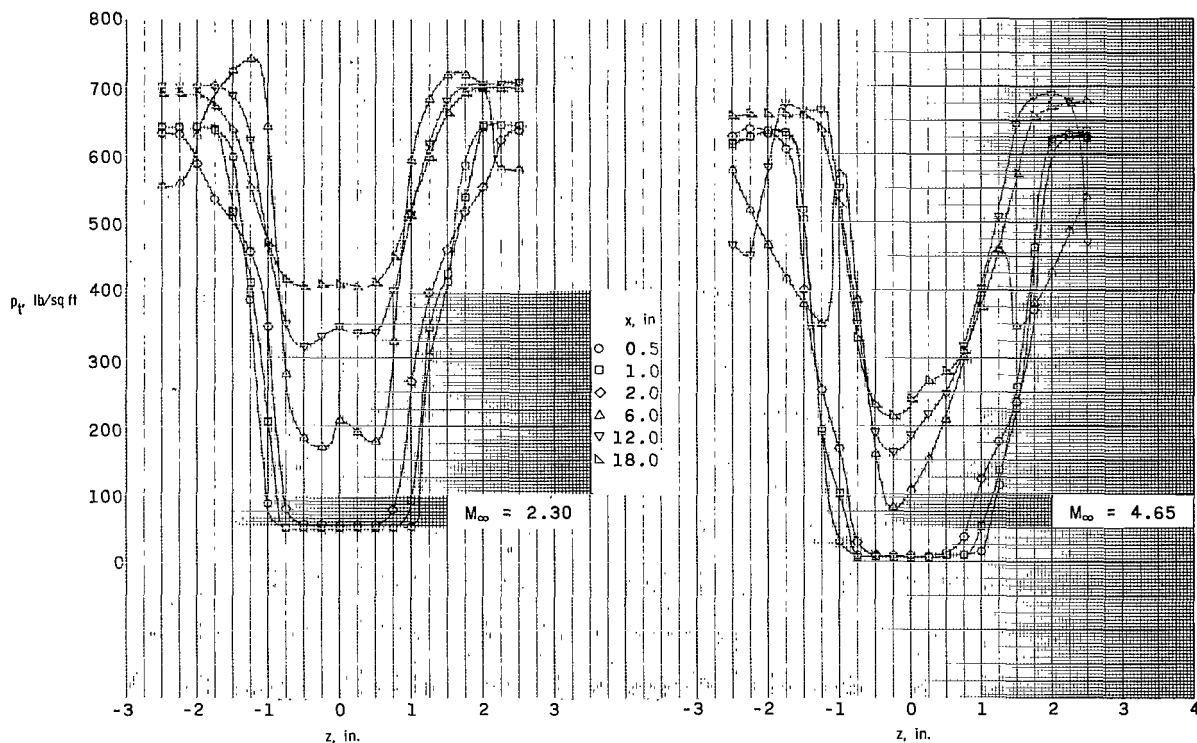


Figure 3.- Vertical distribution of total pressure at various distances behind cone-cylinder. $y = 0$.

free-stream conditions. The erratic changes in pressure at $x = 6$ inches for both Mach numbers are associated with the pressures induced by the expansion wave emanating from the model. The trend may be noted for $M_\infty = 4.65$ up to $x = 12.0$ inches since the trailing shock angle for this Mach number is considerably greater than that for $M_\infty = 2.30$. It should be noted that the velocity of all flow outside the dead-air region at both test Mach numbers is supersonic.

The vertical distribution of total pressure at various lateral distances from the model center line ($y = 0$ to 2.5 inches) is shown in figure 4 for each x location. Local static-pressure measurements are also included in this figure. At values of x up to 2.0 inches, the effect of the cone-cylinder model on the total pressure rapidly dissipates in the lateral plane, particularly outside the area of the model base. At $y = 2.5$ inches, only a small region near $z = 0$ shows a variation in p_t as a result of the support strut; at $x = 2.0$ inches and $M_\infty = 4.65$, even this variation is almost completely eliminated.

The total-pressure data at $x = 6$ inches (fig. 4(d)) for both test Mach numbers and at $x = 12$ inches (fig. 4(e)) for $M_\infty = 4.65$ are very erratic at the various y locations. This instability occurs because some of the pressures are measured in the expansion field behind the model and others are measured in the flow core or inside the trailing shock. At a distance of 18 inches behind the model base, the effect of the cone-cylinder model once again rapidly dissipates with increases in the lateral distance from the model center line, and it is evident that there is little effect of the thin support strut.

These pressure variations downstream of the simulated model base indicate that the problem of obtaining a stable, high-drag decelerator in the supersonic speed regions is difficult, and that the difficulty increases with increasing Mach number because of the greater loss in total pressure near the center line. The data indicate that a decelerator must either be small enough to be completely in a region of relatively constant total pressure at a given distance behind the model, or large enough to have a significant portion of its area at or near stream conditions in order to overshadow any effects of the variations in pressure. Of course the region of the wake throat where the shock-wave expansion from the cone-cylinder model interacts with the trailing shock should be avoided since this region has been found to produce violently unstable characteristics for most decelerators tested to date. (For example, see ref. 6.) The data also indicate that it would be desirable for decelerators to be at large distances from the configuration base (distances larger than 7.5 times the model base diameter), particularly at the high Mach numbers because of the large variation in p_t .

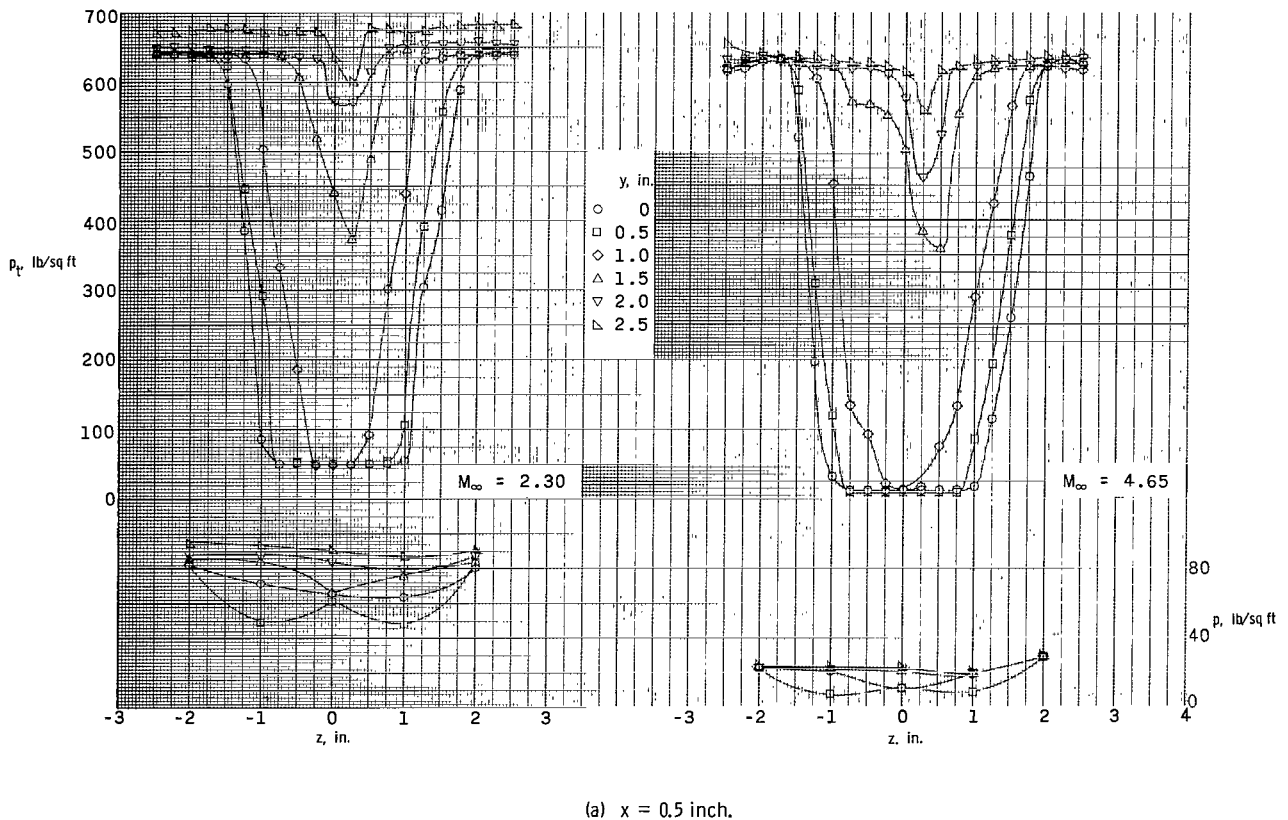
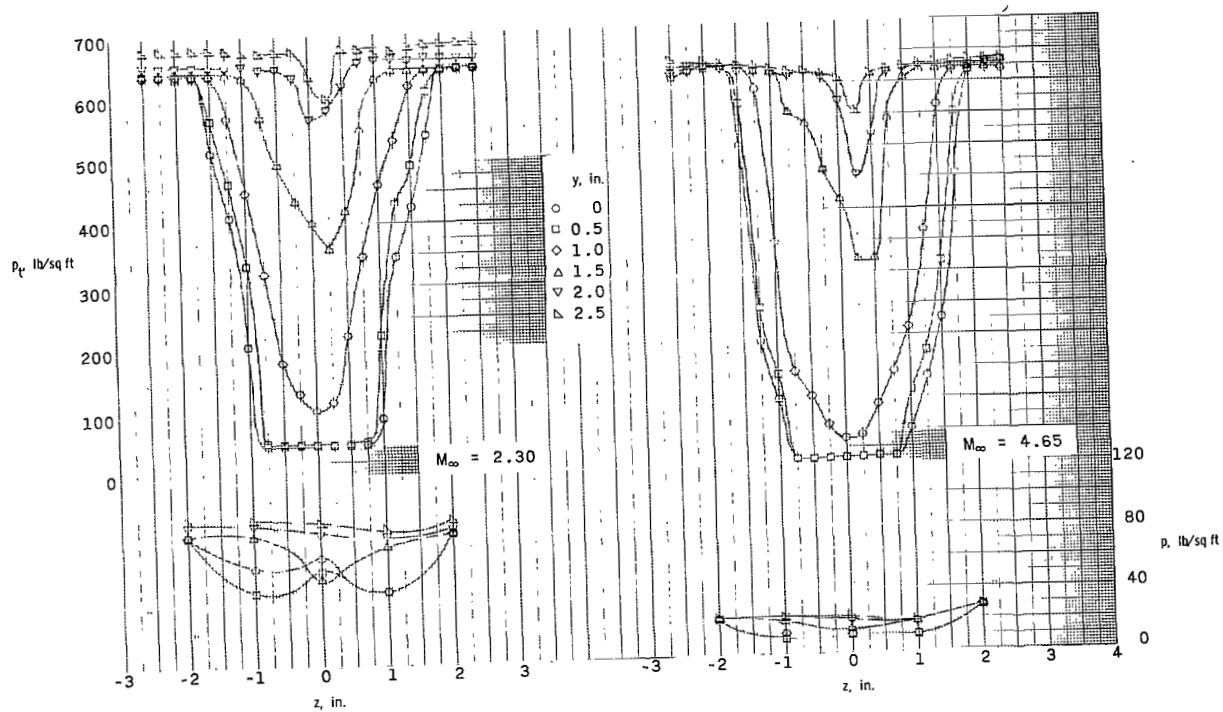
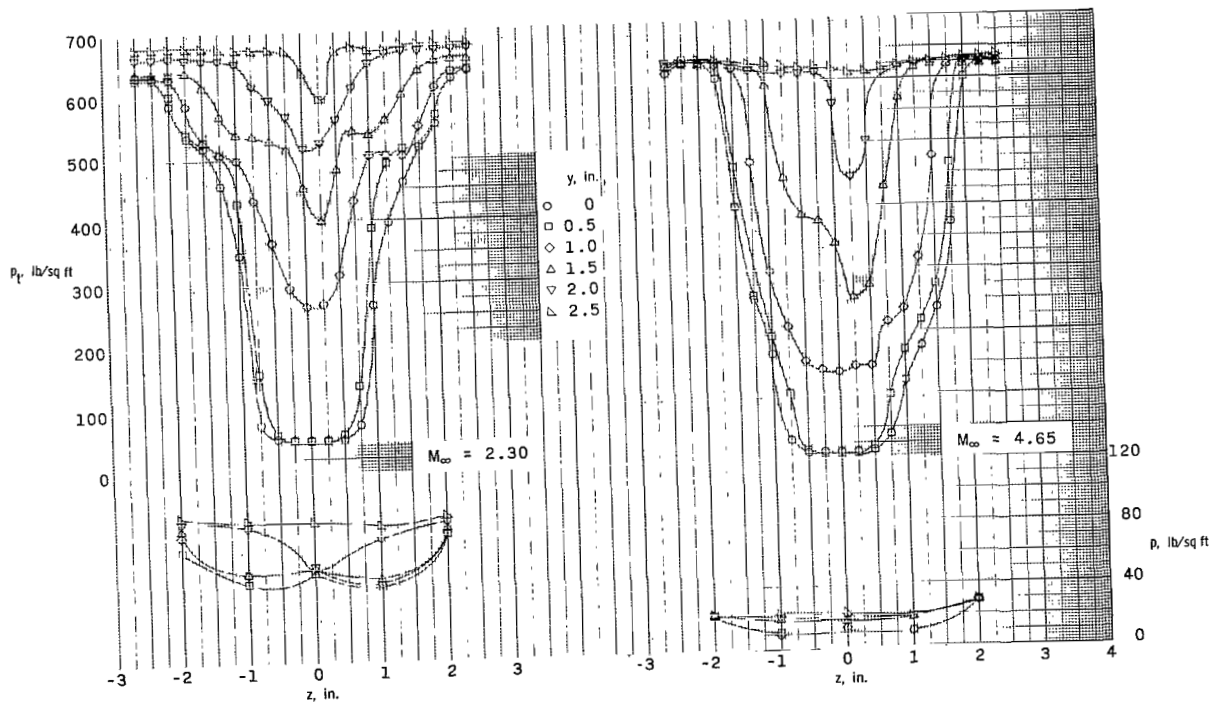


Figure 4.- Vertical distribution of total and static pressure behind cone-cylinder at various lateral distances from center line.

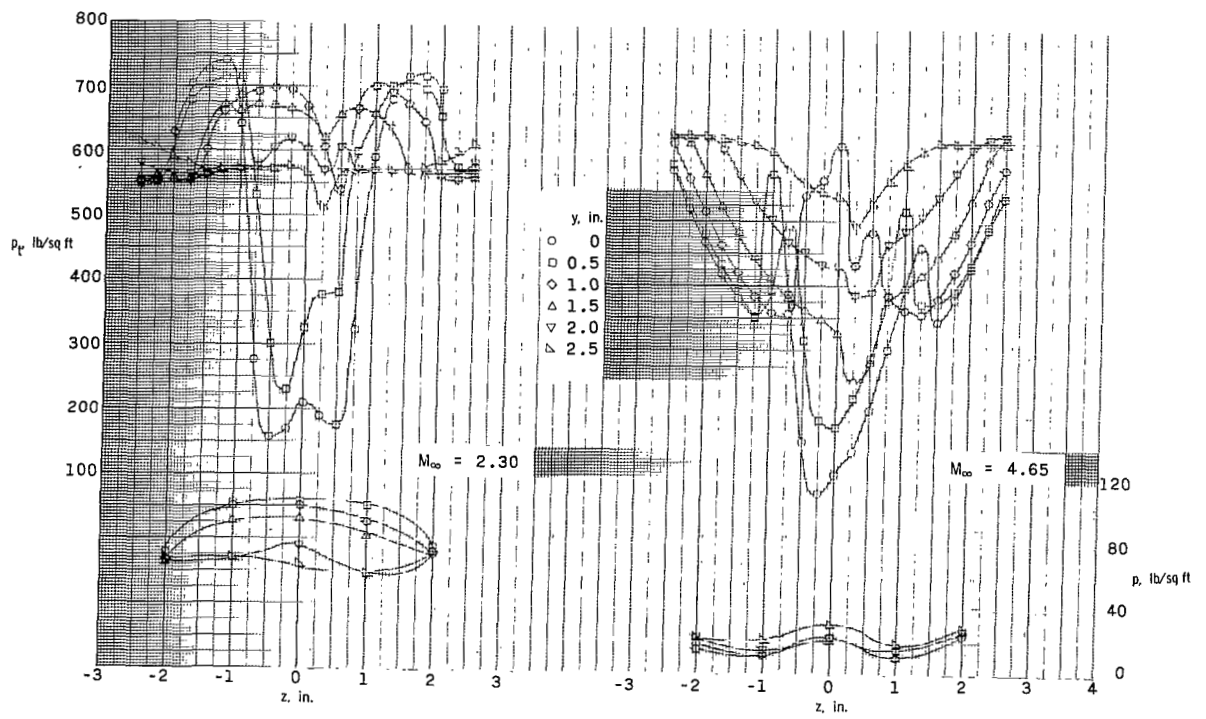


(b) $x = 1.0$ inch.

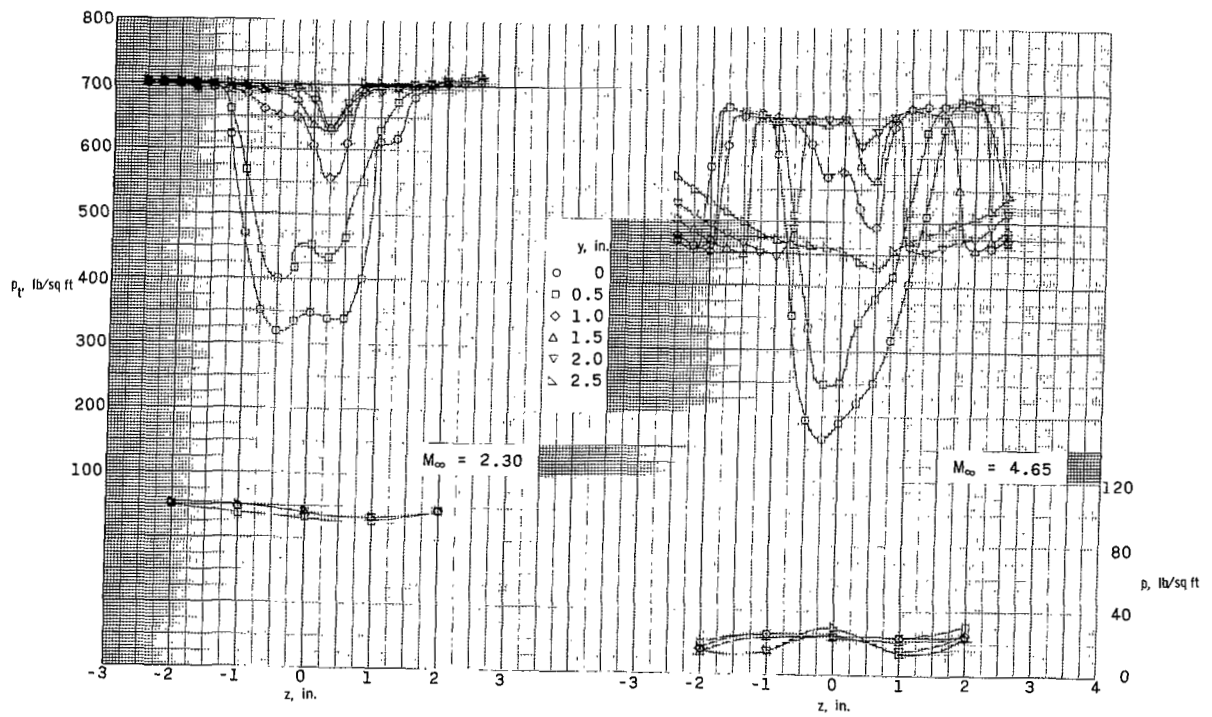


(c) $x = 2.0$ inches.

Figure 4.- Continued.

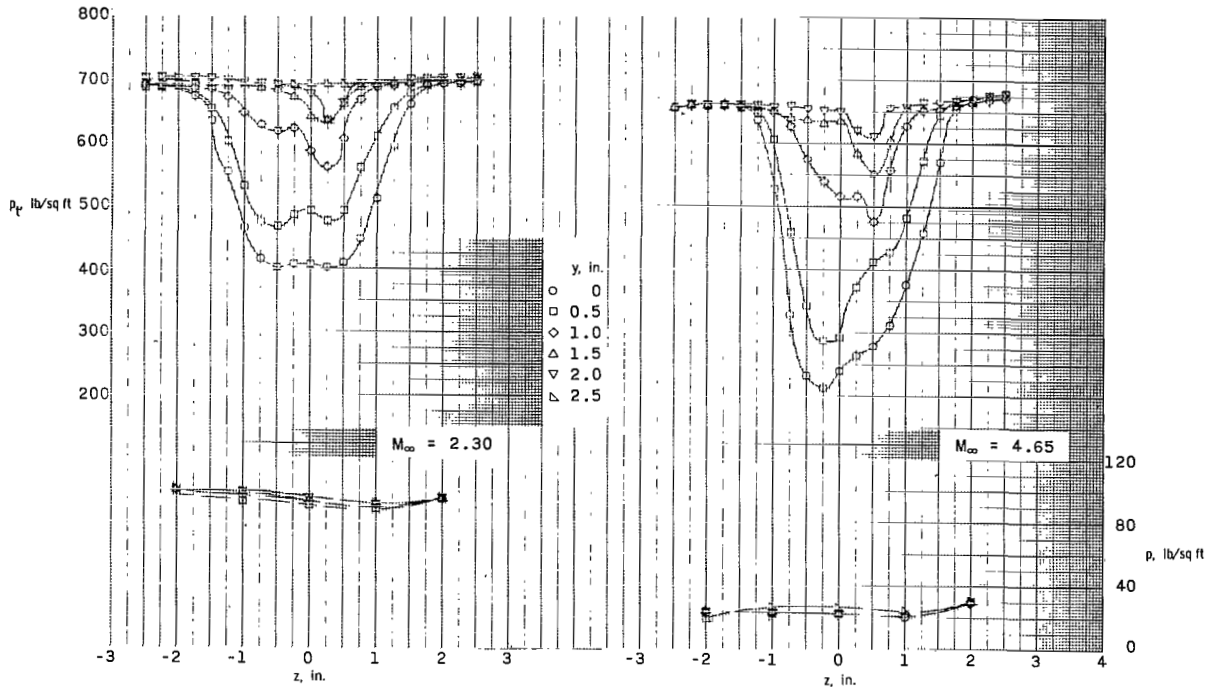


(d) $x = 6.0$ inches.



(e) $x = 12.0$ inches.

Figure 4.- Continued.



(f) $x = 18.0$ inches.

Figure 4.- Concluded.

CONCLUSIONS

Wind-tunnel pressure measurements in the wake of a cone-cylinder body at Mach numbers of 2.30 and 4.65 have been made. The results of the pressure distributions indicated the following conclusions:

1. The use of thin struts to mount the wind-tunnel model had little or no effect on the wake characteristics of the model.
2. The distribution of total pressure in the wake throat region behind the cone-cylinder configuration was extremely nonuniform and such characteristics would exert an unstable influence on a decelerator in the flow field.
3. The total pressure loss near the center line in the wake of the cone-cylinder configuration significantly increased with an increase in Mach number.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 14, 1965.

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